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Relationship of tree growth to climate in the Nechako region of central interior British Columbia

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Abstract

Relationships between tree growth and climate can be found using dendroclimatology, and are important as a basis for understanding regional limiting factors of growth and projecting how forests might be altered by climate change. This study aims to determine factors limiting growth of coniferous trees in the Nechako region of sub-boreal Central-Interior British Columbia by studying tree growth-climate relationships at the Carrot Lake Experimental Fire Study area. Trees cores were collected from the study area in 2012 then processed and analyzed in 2014. Ring-counting of cores from Lodgepole Pine and White Spruce trees indicated samples had ages of 127-136 years. Tree ring chronologies were standardized, verified by cross-dating, and pre-whitened for dendroclimatology analysis. A simple linear regression comparison of ring widths against summer temperature and precipitation data from nearby weather stations showed there was a statistically significant, positive correlation between annual ring growth and precipitation in the month of May (standardized $R^2 = 0.06128$, pre-whitened $R^2 = 0.05635$; $n = 9$). This indicates a growth-precipitation relationship during the beginning of the growing season, where more rain results in greater growth. Due to the small, localized sample size used in this study these findings may only represent the mesoclimate of the Carrot Lake Experimental Fire study site. Nevertheless, this study may be the basis for future research that can provide better insight into the climate history for the region, as well as projections of climate change impacts on the forests of British Columbia.

Keywords — Dendrochronology, Dendroclimatology, Tree ring-growth, Sub-boreal forest

1. INTRODUCTION

KNOWLEDGE of the factors that limit the growth of trees is fundamental to our understanding of forest productivity and how forests may be altered by climate change. Dendrochronology is the study and dating of tree growth rings, which are formed through differing rates of tree cell division, creating the annual alternating light-coloured "earlywood" (late spring–early summer) and dense, dark "latewood" (late summer–early fall) [1]. Dendroclimatology combines dendrochronology and climate data, and is used to examine relationships between tree growth and the environment.

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The cell number and size in earlywood and latewood vary from year to year depending on environmental factors, such as temperature and precipitation, which affect photosynthesis and cell division, thus creating annual variation in growth patterns [2]. This annual variation of ring growth can be used to infer past climate conditions (prior to the instrumental record), such as the precipitation variability across the Great Plains [3] and the southern Canadian Rockies [4] over the past 600 years, or the temperature variability in the Northern Hemisphere over the past 1000 years [5]. Dendroclimatology may also be useful for projecting tree responses to future climate change, such as a potential reduction in Douglas-fir (*Pseudo tsugamenziesii*) productivity at high elevations based on a projected increase in the climate-based heat moisture index [6].

Tree ring width is controlled by sensitivity to the growth component (i.e., water, temperature, light, nutrients) that is least available to the plant – a limiting factor [2]. Ring widths in warmer and wetter regions tend to be less sensitive to climate factors due to more stable environmental conditions, whereas trees in arid environments are often more sensitive to variability in precipitation and trees in cold regions are sensitive to temperature [1]. For example, in Alberta, increased radial growth of Lodgepole Pine (*Pinus contorta*) in mountainous areas is positively associated with early spring temperature and late-summer precipitation [7]. Limber Pine (*Pinus flexilis*) in the Great Plains shows a positive relationship between growth and precipitation in May, June, and August [8].

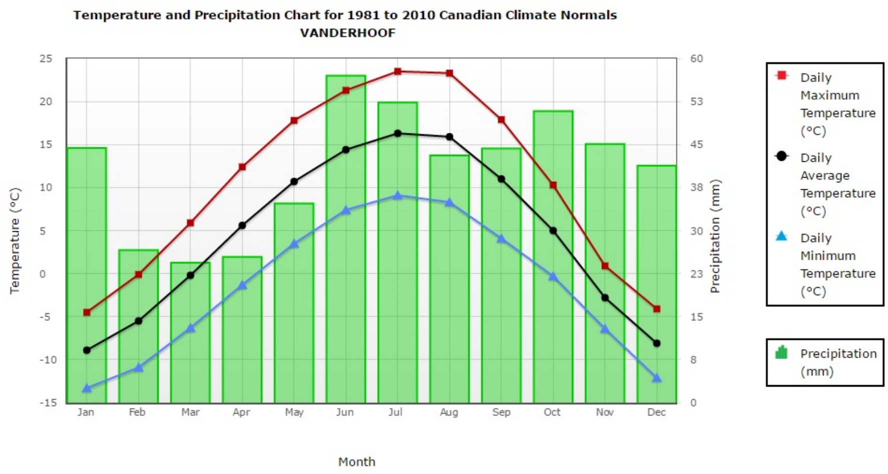

Figure 1: *Average temperature and precipitation data chart based on data from the Vanderhoof weather station, near the study site, from 1981 to 2010 [9]. The months of May to August are considered the growing season in our study. This plot was obtained from the Government of Canada's Climate Normals Data for the Vanderhoof Weather Station [9].*

Although there have been studies done to determine the limiting growth factors and seasonal timing for tree growth across Canada, there are differing results depending on the location of the study [6, 7, 8]. A broad environmental study of the Sub-boreal Spruce Zone of British Columbia (BC) was completed, [10] which detailed general vegetation, soil types, and air temperature patterns in order to characterize environmental factors that affect vegetation growth. However, to our knowledge, no studies have been completed specifically assessing climatic controls on growth for coniferous trees that dominate the forests of the sub-boreal region. The forests in this region experience distinct seasonality in temperature and precipitation (Figure 1), with an average growing season (May to August) temperature of 14.3°C and an average precipitation of 46.8mm [9]. Since the growing season is relatively short, there is reason to believe that this region may have strong limiting factors that affect the growth of trees.

Figure 2: *The Carrot Lake Experimental Fire Study area is located in Central Interior British Columbia, approximately 75km southwest of Vanderhoof, BC. Tree core samples analyzed in this study were taken from plot2, labelled in the figure [11].*

Our study aims to determine the tree growth-climate relationship in the Carrot Lake Experimental Fire Study area located in the Nechako region of sub-boreal forest in Central Interior BC (Figure 2). To determine this, we tested for a correlation between tree growth, via annual ring widths, and annual climatic factors of precipitation and temperature of the growing season months.

2. RESULTS

Annual growth of trees in the study area was positively correlated with May precipitation, based on both standardized and pre-whitened radial tree growth (Table 1). These results can be viewed visually through scatterplots, as illustrated in Figures 3 and 4. Three relationships had test statistics close to the critical p-value of 0.05 (Table 1): standardized growth vs. Klusklus May precipitation, pre-whitened growth vs.Vanderhoof May mean temperature, and pre-whitened growth vs. Vanderhoof June mean temperature.

Table 1: *Calculated R^2, slope estimate, standard error, and p-values from a simple linear regression between monthly mean temperature and precipitation measurements against standardized and pre-whitened radial growth values. Results are shown for data from the Klusklus and Vanderhoof weather station. Statistically significant relationships ($p < 0.05$) are shown in italics.*

Kluskus Weather Station: **Mean Temperature vs. Growth**

	Standardized				**Pre-Whitened**			
Month	R^2	**Est**	**Std err**	p**-val**	R^2	**Est**	**Std err**	p**-val**
May	0	1.51	2.91	0.82	0	-0.52	2.6	0.84
June	0.03	0.67	1.84	0.42	0.01	0.91	1.73	0.61
July	0.01	-0.59	1.77	0.74	0.01	-0.77	1.64	0.65
August	0	0.37	1.39	0.79	0.01	0.44	1.3	0.74

Kluskus Weather Station: **Precipitation vs. Growth**

	Standardized				**Pre-Whitened**			
Month	R^2	**Est**	**Std err**	p**-val**	R^2	**Est**	**Std err**	p**-val**
May	0.15	54.31	30.55	0.09	0.08	34.5	28.41	0.24
June	0.1	-50.97	35.43	0.17	0.13	-54.39	32.37	0.11
July	0.15	57.99	31.59	0.08	0.08	38.19	30.64	0.23
August	0.18	-40.16	33.22	0.24	0.04	-28.61	31.67	0.38

Vanderhoof Weather Station: **Mean Temperature vs. Growth**

	Standardized				**Pre-Whitened**			
Month	R^2	**Est**	**Std err**	p**-val**	R^2	**Est**	**Std err**	p**-val**
May	0.04	-2.42	1.46	0.1	0.05	-3.32	1.67	0.05
June	0.02	-1.9	1.39	0.18	0.04	-2.85	1.59	0.08
July	0	-0.08	1.21	0.95	0	-0.49	1.39	0.73
August	0	0.04	1.34	0.98	0	-0.46	1.53	0.77

Vanderhoof Weather Station: **Precipitation vs. Growth**

	Standardized				**Pre-Whitened**			
Month	R^2	**Est**	**Std err**	p**-val**	R^2	**Est**	**Std err**	p**-val**
May	*0.06*	*0*	*0*	*0.03*	*0.06*	*0*	*0*	*0.04*
June	0.01	0	0	0.32	0	0	0	0.78
July	0.01	0	0	0.5	0.1	0	0	0.49
August	0	0	0	0.78	0	0	0	0.91

3. DISCUSSION

We found a positive correlation between annual tree ring growth and May precipitation. This growth-precipitation relationship coincides with the seasonal timing for the beginning of the growing season in Central Interior British Columbia. A similar sensitivity of tree growth to the early summer environment was found for Lodgepole Pine [7] and

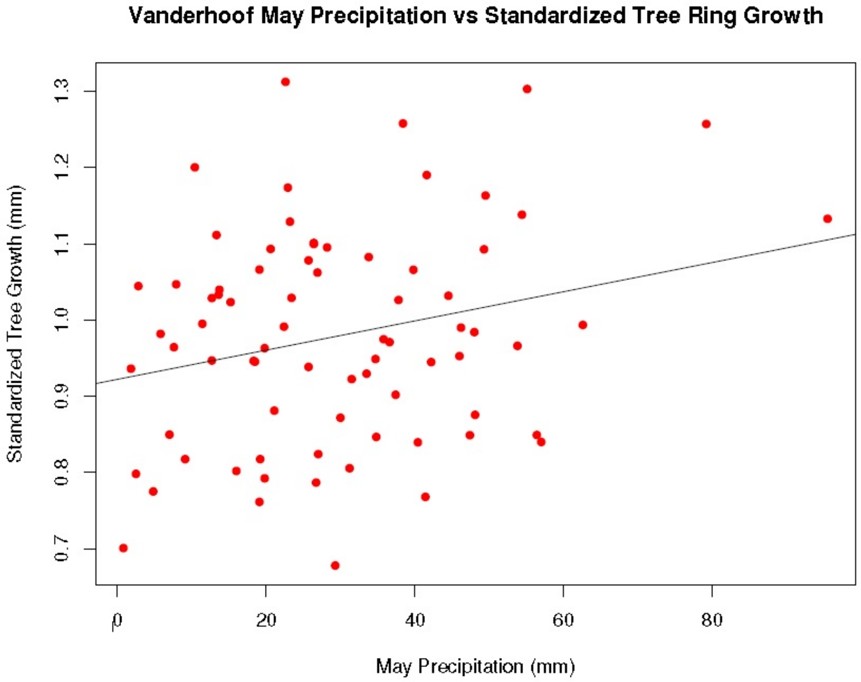

Figure 3: *Scatterplot with slope from a linear regression for annual standardized tree growth of the master chronology plotted against precipitation in May (*$R^2 = 0.0613$*, estimate* $= 0.0019$*, standard error* $= 0.0009$*, p-value* $= 0.0323$*). The relationship is based on precipitation data from the Vanderhoof weather station (1916-2006).*

Limber Pine [8] in mountainous and prairie areas of Alberta. Together, these results suggest early summer conditions play a key role in conifer tree growth across broad regions of western North America.

Dendroclimatology has its associated limitations [12], and certain assumptions were employed in our study in order to address them. First, the two different species sampled, Lodgepole Pine, and White Spruce, were assumed to both grow the same way in response to climate factors, i.e., have the same climate sensitivity. However, pines are generally more efficient at water conservation and also grow better under warmer and drier conditions compared to spruce [13]. Further analysis where each species is analyzed independently would allow us to verify the consistency of response we observed. Secondly, the obtained climate data is assumed to be representative of the study site. Although the nearer Klusklus weather station would likely better reflect the study area's local climate, it had a shorter time series (1992 to 2013) compared to the more distant Vanderhoof weather station (1916 to 2006). Third, no confounding factors are assumed to have influenced the radial growth of the trees aside from temperature and precipitation. However, other climatic factors, such as light availability or above-freezing-degree days, which would provide more energy for increased photosynthesis and growth, were not tested. Finally, the study site is located within a Mountain Pine Beetle (*Dendroctonus ponderosae*) infestation zone and therefore could have other environmental conditions, such as insect damage, that may potentially have an effect on tree growth.

In order for the results of this study to be applied in any future research, the

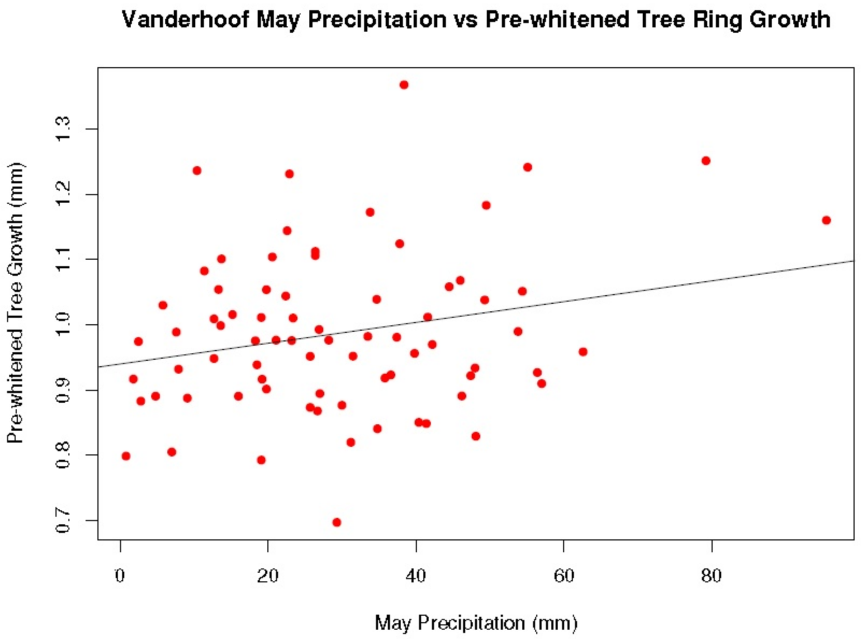

Figure 4: *Scatterplot with slope from a linear regression for pre-whitened growth plotted against precipitation in May (*$R^2 = 0.0564$*, estimate* = 0.0016*, standard error* = 0.0008*, p-value* = 0.0403*). The relationship is based on precipitation data from the Vanderhoof weather station (1916-2006).*

relationship must be confirmed to be an accurate reflection of the region. This study is a preliminary investigation in the tree growth and climate relationship of sub-boreal forests in British Columbia, and contains a small sample size in a single area. Future research to confirm the growth-climate relationship would benefit from having a larger sample size taken across a larger region of the sub-boreal forest, as well as comparison against other climatic factors. Within the samples, separating conifer species may reflect more accurately how different species respond to climatic conditions, and may show differing limiting factors. Given that the average temperature for the region in April and September is above 0°C [9], the growing season months examined could be extended to include late spring and early fall, when earlywood and latewood may be forming. Finally, work by both Chhin et al. [7] and Case and MacDonald [8] also examined the effect of temperature and precipitation from the previous year on the current year's growth and found a negative correlation with late summer temperatures. Future work could include performing this correlation test to include any residual effects from previous years on the tree growth-climate relationship.

4. METHODS

4.1. Study Area

The study area was located at the Carrot Lake Experimental Fire Study in Central Interior BC in the sub-boreal spruce biogeoclimatic zone [14]. The sub-boreal spruce zone is characterized by dense coniferous forests dominated by Lodgepole Pine (*Pinus contorta*), and also includes White Spruce (*Picea glauca*) and Subalpine Fir (*Abies lasiocarpa*) [14]. The region has distinct seasons (Figure 1), allowing for tree ring formation.

Climate data were obtained from two weather stations near the Carrot Lake Experimental Fire Study area and included daily temperature and precipitation data. The Vanderhoof weather station data were available for 1916 to 2006 (90 years), and the Klusklus weather station data were available for 1992 to 2013 (21 years).

4.2. Tree and Core Sample Selection

The tree core samples were taken during the summer of 2012 from sample plots established for the Carrot Lake Experimental Fire Study. Tree core samples were taken from conifer trees in plot 2 (Figure 2), which was approximately 100m by 100m, on relatively flat terrain. The tree cores were taken at the base of each sample tree, from plots located 20m distant from one another. Cores were taken using an increment borer and stored for transport. At the lab, cores were mounted and sanded with progressively finer sandpaper to improve the visibility of narrow or faint growth rings. Of the tree cores taken, nine were selected for analysis based on whether the wood was intact with no disintegration, if the core contained the pith, if the tree was alive, and if the growth pattern did not have sudden growth spurts that would likely not be attributed to climatic conditions, but rather to localized stand dynamics. The cores were selected from 108 samples taken from live Lodgepole Pine and White Spruce trees, aged between 127-136 years.

4.3. Sample Processing

The tree rings were counted and rings widths were measured using a binocular microscope and Velmex^{TM} measuring stage (precise to 0.001mm) along with MeasureJ2X^{TM} software [15]. Each individual ring width was measured perpendicularly to the earlywood-latewood boundary, starting from the bark boundary to the pith. This method built a record of intra-boundary measurements that reflected the annual growth rate and patterns of each tree.

4.4. Chronology Development

We developed a master chronology of the tree ring data for comparison with the climate data. The master chronology was assembled using an iterative cross-dating process with standardized ring width data, then by averaging all the cross-dated width measurements from each tree core sample across each corresponding year to produce a collective of average width measurements showing the inter-annual variability in growth characteristic of trees in the study area. The initial cross-dating process was important to ensure that the tree ring count was accurate and that tree ring widths from identical years were being compared with climatic variation [16]. All analyses, standardization, and the verification process outlined below were done using the dplR library package in the statistical analysis program R [17] and following the steps given in Bunn [18] and Bunn [19].

We used a detrending process that standardized all tree ring width measurements by applying a cubic smoothing spline curve to eliminate the sigmoidal curved signal of

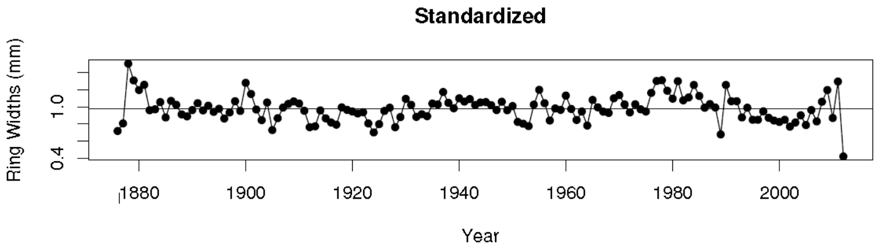

Figure 5: *The master chronology of standardized tree ring width, with the standardized and averaged tree ring width measurements corresponding to the year of growth.*

increased growth that occurs at the beginning of each tree's lifecycle (Figure 5). Using the standardized measurements, a graphic correlation chart (Figure 6) was created that "flagged" segments of core measurements where standardized ring width did not have a high correlation when compared with the current master chronology.

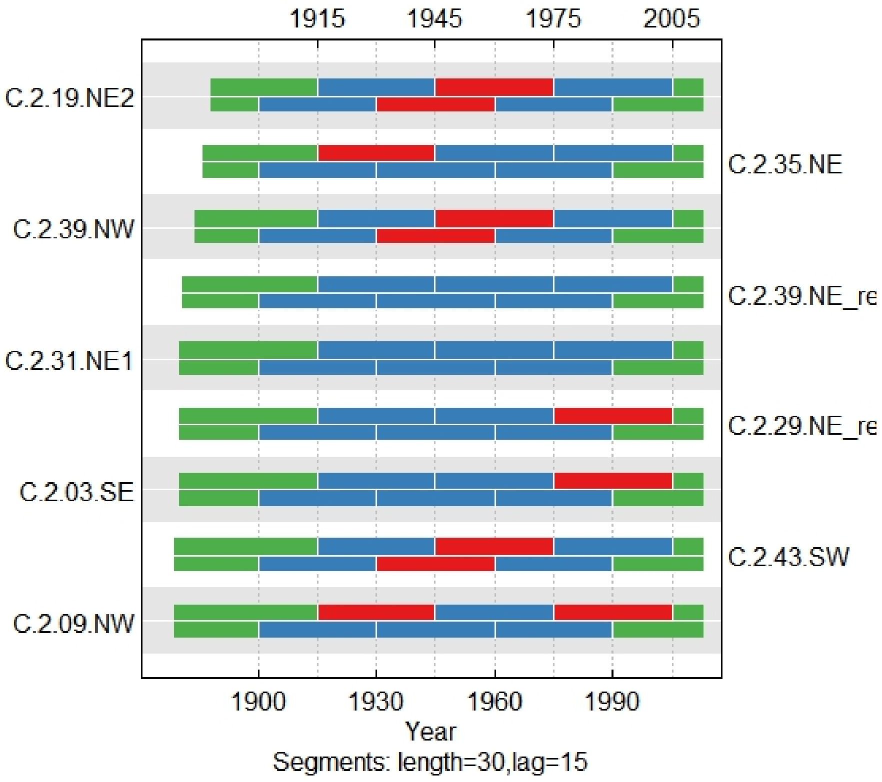

Figure 6: *Graphic correlation chart showing different cores (y-axis) and core segment lengths (x-axis) compared with the master chronology generated by pooling information from all cores together. Blue segments show positive correlations in standardized ring widths, red segments are negative correlations, and green segments lack enough information for correlation. The segment length of 30 years was chosen as it would be long enough for comparison, but short enough to narrow down any negative correlations indicative of offset growth patterns among cores.*

For each "flagged" segment, a lag plot (Figure 7) was used to better visualize the correlation of growth for each year. Shifts in the lag plot may be due to miscounts or a missing ring. Using an iterative process, adjustments were made to the assigned years of the core, e.g., if there were any miscounts or missing rings, by reviewing the tree core and adjusting/correcting dates in the data.

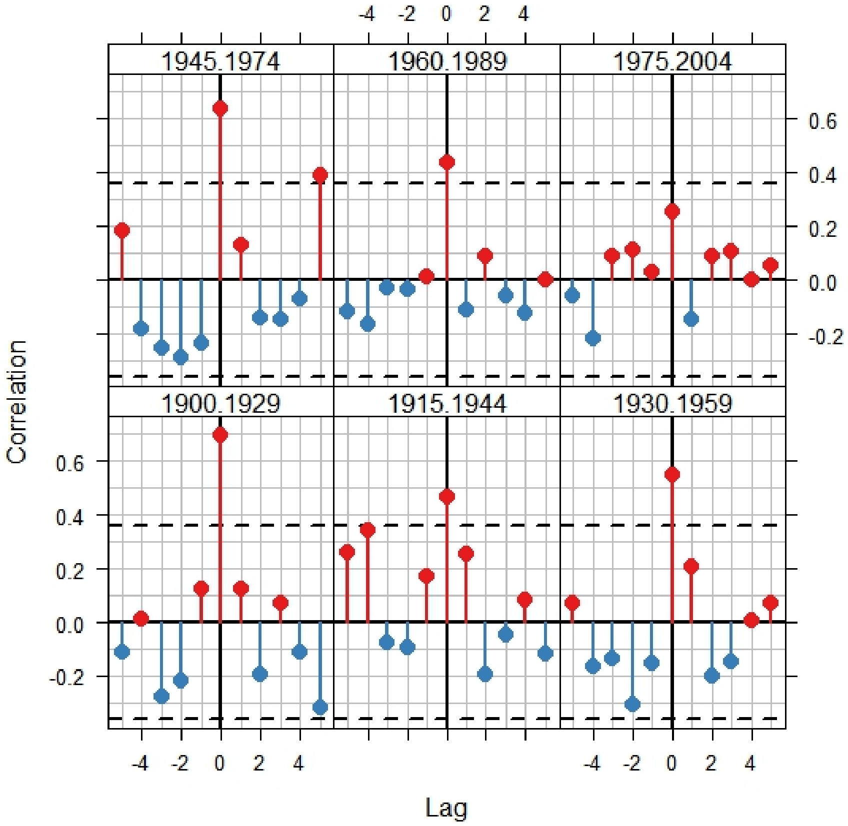

Figure 7: *Lag plot for example core "C-2-03-SE" showing an overall positive correlation in annual growth between the core and the master chronology. Red markers indicate a positive correlation in standardized ring width, and blue markers indicate a negative correlation. Overall, one would expect to see high values of tree ring growth for a particular year occur in years when the pooled, master chronology shows high values; and correspondingly, low values shared between a core and the master. In this example, although there is the lower correlation between 1975-2004, the correlation is still positive, and is thus attributed to the natural variability in growth of the tree, and not due to miscounting or incorrect dating.*

After any low correlations were verified to be variation in growth of the individual trees and not due to miscounts, the master chronology verification was complete. Each core's standardized measurement was then pre-whitened as a second standardization step where autocorrelation, or any influence on growth due to previous year growths, is removed from each series before averaging the width measurements.

The final, verified master chronology measurements of tree ring growth were correlated against mean temperature and mean precipitation for the months of the growing season of all operating years of the weather stations (Vanderhoof: 1916-2006, Klusklus:

1992-2013). A simple linear regression for tree ring growth vs. temperature and tree ring growth vs. precipitation in May, June, July, and August for both Vanderhoof and Klusklus weather stations was performed. We created visual graphs and used a *t*-test to determine whether we should reject the null hypothesis, and these suggested the estimated slope of the relationship was statistically different from zero, at alpha $= 0.05$. No Bonferroni correction of significance was used in this analysis.

5. Conclusions

The results of this study indicate that conifer tree growth responds to May precipitation in the Nechako region of the sub-boreal forest of British Columbia. The growth and May precipitation relationship allows for a historical estimate of precipitation going back beyond weather station operating years, based on tree ring data. This long-term record can provide insight into the regional climate history. Thinking to the future, annual mean temperatures are projected to increase by 2-4°C,and annual precipitation is expected to increase in North America by the end of the 21st century [20]. The growth-precipitation relationship allows us to make an educated guess at how coniferous trees in the British Columbian sub-boreal forest may respond to climate change; with increased precipitation we may see increased growth.

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References

[1] Harold C Fritts. Dendroclimatology and dendroecology. *Quaternary Research*, 1(4): 419–449, 1971. doi:10.1016/0033-5894(71)90057-3.

[2] James H Speer. *Fundamentals of tree-ring research*. University of Arizona Press, 2010.

[3] Scott St George and Erik Nielsen. Hydroclimatic change in southern Manitoba since ad 1409 inferred from tree rings. *Quaternary Research*, 58(2):103–111, 2002. doi:10.1006/qres.2002.2343.

[4] Emma Watson and Brian H Luckman. Dendroclimatic reconstruction of precipitation for sites in the southern Canadian Rockies. *The Holocene*, 11(2):203–213, 2001. doi:10.1191/095968301672475828.

[5] Jan Esper, Edward R Cook, and Fritz H Schweingruber. Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. *science*, 295(5563):2250–2253, 2002. doi:10.1126/science.1066208.

[6] PEI-YU CHEN, Cedar Welsh, and Andreas Hamann. Geographic variation in growth response of Douglas-fir to interannual climate variability and projected climate change. *Global Change Biology*, 16(12):3374–3385, 2010. doi:10.1111/j.1365-2486.2010.02166.x.

[7] Sophan Chhin, EH Hogg, Victor J Lieffers, and Shongming Huang. Influences of climate on the radial growth of lodgepole pine in Alberta. *Botany*, 86(2):167–178, 2008.

[8] Roslyn A Case and Glen M MacDonald. A dendroclimatic reconstruction of annual precipitation on the western canadian prairies since ad 1505 from pinus flexilis james. *Quaternary Research*, 44(2):267–275, 1995. doi:10.1006/qres.1995.1071.

[9] Government of Canada. Canadian climate normals 1981-2010 station data: Vanderhoof, BC, 2016. URL `http://climate.weather.gc.ca/climate_normals/index_e.html`.

[10] Mohan Kishen Wali and VJ Krajina. Vegetation-environment relationships of some sub-boreal spruce zone ecosystems in British Columbia. *Vegetatio*, 26(4-6):239–381, 1973. doi:10.1007/BF02389538.

[11] Google Earth. Carrot Lake Experimental Fire Study Site, British Columbia, Canada. 53° 23′ 57.89"N, 151° 25′ 44.82"W, eye alt 4.21 km. Cnes/Spot Image, 2014.

[12] Malcolm K Hughes. Dendrochronology in climatology–the state of the art. *Dendrochronologia*, 20(1):95–116, 2002. doi:10.1078/1125-7865-00011.

[13] Christof Bigler, Daniel G Gavin, Charles Gunning, and Thomas T Veblen. Drought induces lagged tree mortality in a subalpine forest in the Rocky Mountains. *Oikos*, 116(12):1983–1994, 2007. doi:10.1111/j.2007.0030-1299.16034.x.

[14] BC Ministry of Forests. Sub-Boreal Spruce Zone. *BC Special Report Series*, pages 209–221, 1991. URL `https://www.for.gov.bc.ca/hfd/pubs/docs/srs/Srs06/chap14.pdf`.

[15] VoorTech Consulting. MeasureJ2X, 1998. URL `http://www.voortech.com/projectj2x/`. Holderness, NH, USA: ProjectJ2X.

[16] Andrew E Douglass. Crossdating in dendrochronology. *Journal of Forestry*, 39(10): 825–831, 1941.

[17] R Core Team. R: A language and environment for statistical computing. vienna, austria: R foundation for statistical computing; 2014, 2014. URL `http://www.R-project.org/`.

[18] Andrew G Bunn. A dendrochronology program library in R (dplR). *Dendrochronologia*, 26(2):115–124, 2008. doi:10.1016/j.dendro.2008.01.002.

[19] Andrew G Bunn. Statistical and visual crossdating in R using the dplR library. *Dendrochronologia*, 28(4):251–258, 2010. doi:10.1016/j.dendro.2009.12.001.

[20] CB Field, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, et al. Contribution of working group ii to the fifth assessment report of the intergovernmental panel on climate change. *Climate change*, 2014.